Geel 2000 Language schools

Physics

Sec.2

Sec.term (2022 / 2023)

UNIT (2)

CHAPTER (3)

CHARACTERISTICS OF FLUIDS AT REST. (STATIC FLUIDS)

1. Density:(ρ)

Is the mass of the material per unit volume.

$$\boxed{Density\ (\rho) = \frac{mass\ (m)}{Volume\ (Vol)} \rightarrow \frac{kg}{m^3} \rightarrow [M L^{-3}]}$$

ex: Al 2700 kg / m^3 Ag 10500 kg / m^3 Fe 7900 kg / m^3

Pb 11400 kg / m^3 Cu 8900 kg / m^3 Au 19300 kg / m^3

2. Specific gravity: (Relative density) (Specific weight)

-Is the ratio between the density of the material & that of water at the same t °.

-Is the ratio between a certain mass of the substance & the mass of an equal volume of water at the same temperature.

- **It has no unit** since it is a ratio.

N.B : - **Density is a characteristic for the material.**

- **Density is inversely proportional to the temperature.**

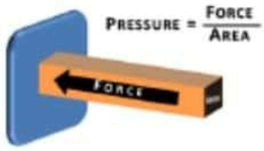
- **In mixtures and alloys : $m_t = m_1 + m_2$**

($\rho_t\ vol_t = \rho_1\ vol_1 + \rho_2\ vol_2$).

Applications on Density

1. Measuring the density of the electrolyte in the accumulator can be used to identify its state. As density decreases on discharging due to the conversion of H_2SO_4 into $PbSO_4$ and re-increases on recharging.
2. The measurement of the blood's density may be used to identify some diseases such as Anemia where the blood density decreases due to the lack of RBCs. (Normal density 1040 – 1060 kg/m^3).Also some diseases may raise the concentration of urine density (1020 kg/m^3) due to the increase of the amount of salts.

3. Pressure: (P)



Is the force acting perpendicular per unit area.

$$\boxed{P=\frac{F}{A}\rightarrow\frac{N}{m^2}\;(\,Pascal\;-kg\,m^{-1}s^{-2})\rightarrow\left[M\,L^{-1}T^{-2}\right]}$$

- If the force is inclined by an angle (θ) to the perpendicular

$$\boxed{P=\frac{F\cos\theta}{A}}$$

N.B : Pressure of an elephant's foot is less than that of a pointed healed shoe.

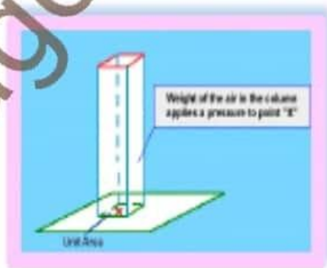
Camel has broad pads.

The edge of a knife is sharp.

The needle is pointed.

Pressure inside a fluid & how it is measured (Hydraulic pressure)

The pressure acting on a point lying on the plane (X) of area (A) found at a depth (h) from the liquid surface is expressed as:



$$P=\frac{weight\;of\;the\;liquid\;column\;above\,(X)}{Area\,(A)}$$

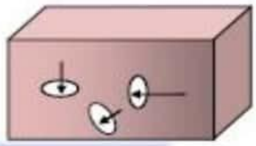
$$P=\frac{m\times g}{A}=\frac{\rho\,vol\,g}{A}=\frac{\rho A h g}{A}=\rho g h$$

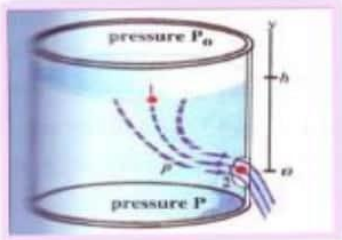
$$\boxed{P=\rho g h\rightarrow\frac{N}{m^2}\;(\frac{J}{m^3}-Pascal-kg\,m^{-1}s^{-2})\rightarrow\left[M\,L^{-1}T^{-2}\right]}$$ **For closed vessels.**

N.B:- The relation expresses the pressure exerted by the liquid only (in a closed container), but if the surface is exposed to the atmosphere it is then affected by the atmospheric pressure (P_a) and the relation becomes: $\boxed{P_t = P_a + \rho g h}$ (for opened vessels) and is called **absolute pressure.**

- The total pressure exerted on a point inside a static liquid is proportional to its depth (h) and the density (ρ) of the liquid regardless to the area (A) or the shape of the container.

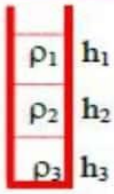
- Pressure acts in all directions at a point inside a liquid.
- Pressure is the same at all points lying on the same horizontal level.



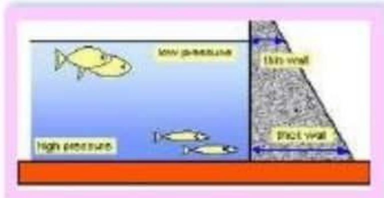


- The absolute pressure in case of many immiscible liquids placed together in a container is calculated as : $P_t = P_a + P_1 + P_2 + P_3$

$$= P_a + \rho_1 g h_1 + \rho_1 g h_2 + \rho_1 g h_3$$

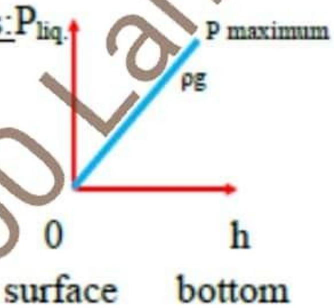


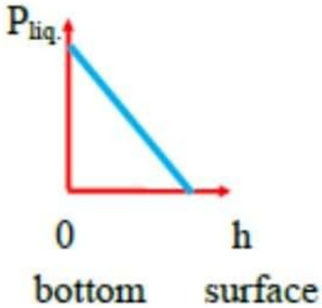
- The base of the dam's wall must be thicker than its top to be able to withstand the higher pressure to which it is exposed as $P \propto h$ (depth).



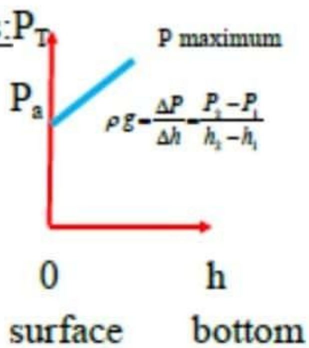
*** Graphs used to show the relation between P & h in a liquid:**

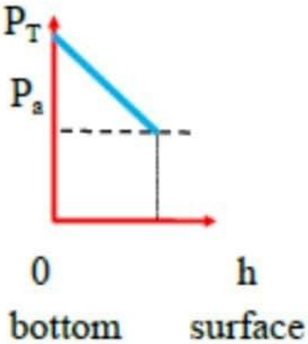
1. In closed vessels:





2. In opened vessels:



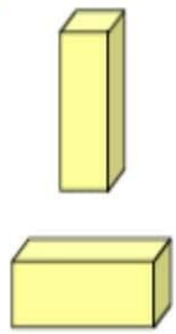


*Solved example:

1. A solid parallelogram of dimensions 5, 10 & 20 cm & density 5000 kg/m^3 is placed on a flat surface . Calculate its maximum & minimum pressures (g = 10 m/s^2).

$$\text{Max. P.} = \frac{F}{A} = \frac{5\times10\times20\times10^{-6}\times5000\times10}{5\times10\times10^{-4}} = 10^4\ N/m^2$$

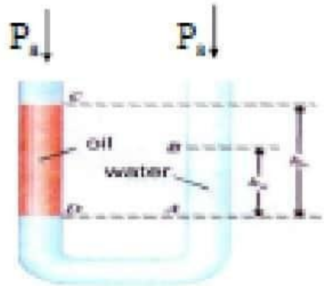
$$\text{or } P_{max} = \rho g h_{max} = 5000\times10\times20\times10^{-2} = 10^4\ N/m^2$$



$$\text{Min.P.} = \frac{F}{A} = \frac{5\times10\times20\times10^{-6}\times5000\times10}{10\times20\times10^{-4}} = 2500\ N/m^2$$

$$\text{or } P_{min} = \rho g h_{min} = 5000\times10\times5\times10^{-2} = 2500\ N/m^2$$

* Balance of liquids in a U shaped tube:



- Pour some H_2O in the U tube, the level of H_2O in both branches will be similar since pressure on both sides is equal to the P_a .
- Pour in one branch oil which is immiscible with water & consider two points (D) at the interface and (A) at the same level .
- Oil reaches a height (h_{oil}) above the point (D) while water reaches a height (h_w) above the point (A) .
- P of the column AB = P of the column CD

$$P_a + \rho_w g h_w = P_a + \rho_{oil} g h_{oil}$$

$$\rho_w h_w = \rho_{oil} h_{oil}$$

$$\boxed{\frac{\rho_o}{\rho_w} = \frac{h_w}{h_o} = \rho_{rel.oil}}$$

- By measuring h_w & h_{oil}, the specific gravity of oil can be calculated.
- The device can be used also to prove that for different liquids to obtain an equal pressure $\boxed{\rho \propto \frac{1}{h}}$

*Solved example:-

1- The cross sectional area of the narrow side of a U tube is 1 cm^2, while that of its wide side is 2 cm^2. The tube is partially filled with water of density 1000 kg/m^3, then a quantity of oil of density 800 kg/m^3 was poured in the narrow side until its height reached 5 cm. Calculate the height of water upon the separating level between oil & water.

$$\rho_1 g_1 h_1 = \rho_2 g_2 h_2$$

$$\rho_1 h_1 = \rho_2 h_2$$

$$h_2 = \frac{\rho_1 h_1}{\rho_2} = \frac{800 \times 5}{1000} = 4 cm.$$

2-A U-shaped tube of cross sectional area $2cm^2$ has an amount of water. $9cm^3$ of kerosene has been poured in one side, so the height difference of water in the two sides is 3.6cm. Find the volume of benzene poured in the other side till the level of water becomes the same in the two sides. $\rho_{H2O} = 1000\,kgm^{-3}$, $\rho_{benzene} = 900\,kgm^{-3}$

v= 9cm³

$$h_k = \frac{V_k}{A} = \frac{9}{2} = 4.5 cm$$

$$\frac{\rho_k}{\rho_{H2O}} = \frac{h_{H2O}}{h_k}, \quad \frac{\rho_k}{1000} = \frac{3.6}{4.5}, \quad \rho_k = 800\,kg/m^3$$

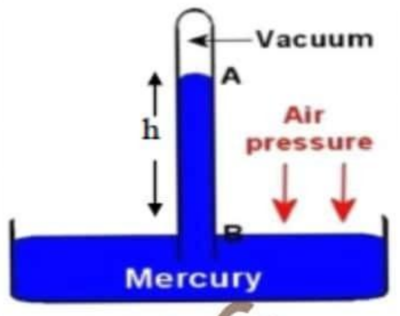
$$\frac{\rho_k}{\rho_b} = \frac{h_b}{h_k}, \quad \frac{800}{900} = \frac{h_b}{4.5}, \quad h_b = 4 cm.$$

$$Vol_b = A \times h = 2 \times 4 = 8 cm^3.$$

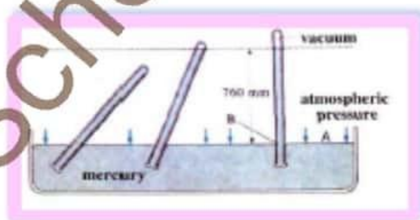
Atmospheric pressure:

Is due to the weight of an air column of unit cross-sectional area and height equal to that of the atmosphere, can be **measured using the Torricellian (Hg)barometer.**

- Mercury barometer (Torricelli)



- A glass tube , one m. long filled with Hg and inverted in a basin filled with mercury.
- The mercury in the tube starts to fall down leaving a space called (Torricellian space where P = 0).
- The atmospheric pressure is equal to the pressure of the mercury column whose height is equal to the difference between the Hg levels in and out of the tube.
- Consider two points (A) & (B) at the same level ,one inside and the other outside the tube .



- Since $P_A = P_B = P_a$
- Therefore $P_a = \rho\, g\, h\,(Hg) + 0\,(\text{vacuum})$
- Since $h = 0.76$ m & $\rho_{Hg} = 13595\ kg/m^3$.
- Therefore $P_a = 0.76 \times 13595 \times 9.8 = \mathbf{1.013 \times 10^5\ N/m^2}$**. or Pascal.**

N.B: 1 bar = 10^5 Pascal = $10^5\ N/m^2$.

N/m^2(Pascal) $1.013\times10^5 \times$ $\boxed{(P_a) = 1\text{Atm}}$ $\times$ 76 cm.Hg

1.013 bar ; 760 mm.Hg (Torr)

$P_a = 1.013 \times 10^5$ Pascal = $1.013 \times 10^5\ N/m^2$ = 1.013 bar

= 760 torr (mm.Hg) = 76 cm.Hg = 0.76 m.Hg = 1 atm.(atmosphere).

- If the tube is inclined the volume of the Torricellian space decreases while the height of the Hg column isn't changed as **P α h** only regardless to the shape and area of the tube.

Standard atmospheric pressure: is equivalent to the pressure exerted by a Hg column of 1 m^2 in section and 0.76 m height at 0 °C at sea level.

N.B :When dealing with Hg ,pressure can be calculated as:

$P_t = P_a$(in cm.Hg) + h of a Hg column.

Ex: Absolute pressure on the base $\mathbf{P_t = P_a + h = 76 + 10 = 86}$ **cm.Hg.**


Hg

***Solved example:-**

1. Find the total pressure & the total force acting upon the base of a tank containing salt water whose density is 1030 kg/m^3, if the cross sectional area of the tank is 1000 cm^2, the water height is 1m and its surface is exposed to air, $g = 10\ m/s^2$ &
$P_a = 1.013 \times 10^5\ N/m^2$.

$$P = P_a + \rho g h = 1.013 \times 10^5 + 1030 \times 10 \times 1 = 1.116 \times 10^5\ N/m^2$$
$$F = P \times A = 1.116 \times 10^5 \times 1000 \times 10^{-4} = 1.116 \times 10^4\ N$$

2. In the fig. the cross section of the opened tube (a) of length 2.5m is 100 cm^2. Find the absolute force acting on each side of the cubic container whose side is 2m long, if water fills it to the top of the tube.
($P_a = 10^5\ N/m^2$, water density is 1000 kg/m^3, $g = 10 m/s^2$.)

$$F = P \times A$$
$$Base = F = (P_a + \rho g h_1) \times Side^2 = (10^5 + 1000 \times 10 \times 4.5) \times 2^2 = 580000\ N$$
$$Side = F = (P_a + \rho g h_2) \times Side^2 = (10^5 + 1000 \times 9.8 \times 3.5) \times 2^2 = 540000\ N$$
$$Top = F = (P_a + \rho g h_3) \times (Side^2 - a) = (10^5 + 1000 \times 9.8 \times 2.5)(2^2 - 100 \times 10^{-4})) = 498750\ N$$

3. A submarine is located horizontally in sea water, the interior of the submarine is maintained at sea level atmospheric pressure. Find the force acting on one of the submarine's windows of circular shape of radius 21 cm and whose center is at depth of 50 m from sea level if the density of sea water is $1030\ Kg/m^3$. ($g = 10\ m/s^2$)

$$F = P_T \times A$$
$$= \cancel{P_a} + \rho g h - \cancel{P_a} \times A$$
$$= \rho g h \times \pi r^2$$
$$= 1030 \times 10 \times 50 \times \pi (21 \times 10^{-2})^2$$
$$= 71350.28\ N$$

4. The table represents the values of pressures at different depths inside a liquid:-

Pr.(Bar)	1.013	1.093	1.173	1.253	X	1.413	1.493	1.573
Depth(m)	0	1	2	3	4	5	6	7

-Draw a graphical representation to show (P) on the ordinate & (h) on the abscissa.

Then find:-

1. The density of water. 2. Pressure at (X). ($g = 9.8\ m/s^2$).

1. $\rho_{H2O} = \dfrac{\Delta P}{\Delta h \times g} = \dfrac{(1.093-1.013)\times10^5}{(1-0)\times9.8} = 816.32\ Kg/m^3$.

2. $P_X = P_a + \rho g h = 1.013\times10^5 + (816.32\times9.8\times4)$

$P_X = 1.332\times10^5\ N/m^2 = 1.332\ bar.$

*** Determination of the pressure of an enclosed gas:**

- Manometers: (pressure gauge):

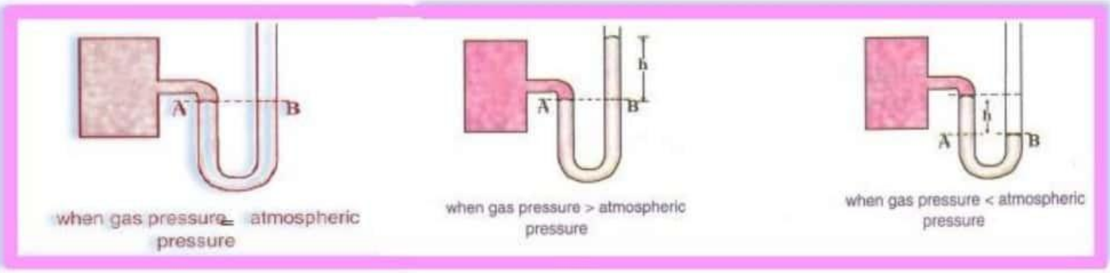
- Devices used to measure the pressure difference (ΔP) between that of an enclosed gas and P_a. or to calculate the absolute pressure of an enclosed gas , when knowing P_a .

- The liquid used to separate both the gas and air in the U tube is Hg , **in case of big pressure differences & H_2O of low density, in case of small differences.**

As for the same ΔP, $\rho \,\alpha\, \dfrac{1}{\Delta h}$

- The cross section of the tube doesn't affect the pressure.

- Consider two points (A) & (B) at the same level.



$P_g = P_a$	$P_g > P_a$	$P_g < P_a$
$P_g = P_a$	$P_g = P_a + \rho g \Delta h$	$P_g = P_a - \rho g \Delta h$
$P_g - P_a = 0$	$P_g - P_a = \rho g \Delta h$	$P_g - P_a = -\rho g \Delta h$

$$\boxed{\therefore P_g - P_a = \pm \rho g \Delta h \rightarrow N/m^2 \ (Pascal)}$$

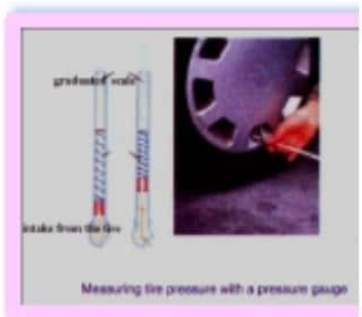
- Note: ΔP can be calculated in cm Hg as $\Delta P = P_g - P_a = \Delta h$ in cm Hg, only if Hg is used.

- Controlling the quantity of air in the **Eustachian canal**, controls the pressure on the ear drum.

* This is done by swallowing or chewing a gum.

<u>Applications on pressure:</u>

1. Blood flows through arteries and veins in a steady flow which may change into turbulent flow producing noise detected by the stethoscope. When the cardiac muscle contracts blood pressure is **120 mm Hg** & is called **Systolic pressure** and when it is relaxed pressure becomes **80 mm Hg** and is called **Diastolic pressure.**



Measuring tire pressure with a pressure gauge

2. As a tire is well inflated (high pressure) the area in contact with ground decreases , while it increases when it is under inflated, this leads to the increase of friction & overheating of the tire. (Measured by the **pressure gauge**)

-N.B:

Pressure devices are all based scientifically on:

1. Two or more points inside the same liquid and affected by equal pressures must be at the same horizontal level.

2. Inside the same liquid $P = \rho g h$ where $p \propto h$ and is independent of the shape and area of the container.

1- What is meant by:

1. The density of mercury is 13600 kg/m^3.

- 13600 kg is the mass of mercury per unit volume (1 m^3)

2. The specific gravity of aluminium is 2.7

- 2.7 is the ratio between the density of Al & that of water at the same temperature.

3. The pressure on a point is 50 N/m^2.

- 50 N is the force acting normally per unit area (1 m^2) around that point.

4. The atmospheric pressure is equal to 76 cm Hg.

- The atmospheric pressure is equal to the pressure exerted by a mercury column of unit area and height equal to 76 cm at 0° C at sea level.

2-Give reasons for:

1. Density is a characteristic for the substance.

- Because density is the mass of the substance per unit volume which depends on the chemical structure (type & number of atoms & bonds …) which differ from a substance to another.

2. Fluids can flow while solids can't.

- Because Fluids have moderate or weak intermolecular attractive forces & wide spaces while solids have closely packed molecules with strong intermolecular attractive forces & narrow spaces so the have definite shapes.

3. Solids are more dense than liquids.

- Because in solids molecules are closely packed so the mass per unit volume is greater than in liquids & density = mass / volume.

4. The edge of a knife is thin.

- Because P = F / A & as area decreases, pressure increases to become high enough to cut an object.

*** Solved examples:**

1. A Hg manometer is used to measure the pressure of a gas inside a container . The Hg level in the free side was higher than the one in the side attached to the container by 36 cm. Find the pressure of the gas enclosed in cm.Hg, P_a and N/m^2.

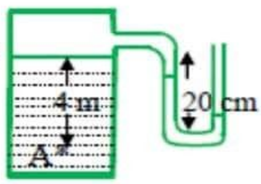
$P_a = 1.013 \times 10^5 \ N/m^2 = 76$ cm.Hg

a) $P = P_a + h = 76 + 36 = 112$ cm.Hg.

b) $P = \frac{P_{in\ cm.Hg}}{76} = \frac{112}{76} = 1.474\ P_a$.

c) $P = P$ in $P_a \times 1.013 \times 10^5 = 1.474 \times 1.013 \times 10^5 = 1.493 \times 10^5\ N/m^2$.

2. If the relative density of the liquid in the tank joined to the Hg manometer is 0.8.Find the pressure at the point A. ($g = 10 m/s^2$, $P_a = 10^5\ N/m^2$, $\rho_{Hg} = 13600\ kg/m^3$).



$$P_g - P_a = -\rho g \Delta h$$

$$P_g = P_a - \rho g \Delta h = 10^5 - (13600 \times 10 \times 0.2) = 72800\ N/m^2$$

$$P_A = P_g + \rho g h = 72800 + (800 \times 10 \times 4) = 104800\ N/m^2$$

Guide rules for problems

*Density:

$$\rho = \frac{mass}{vol.}$$

-Specific gravity :(Relative density):-

$$\rho = \frac{\rho_{sub}}{\rho_{h2o}} = \frac{m_{sub}}{m_{of-vol.ofh2o}} = \frac{Wt_{sub}}{Wt_{of-v.ofh2o}}.$$

-In mixtures and alloys:

$$m_t = m_1 + m_2 \quad OR \quad \rho_t Vol_t = \rho_1 Vol_1 + \rho_2 Vol_2$$

*Pressure:

$$\mathrm{P} = \frac{F}{\mathrm{A}} = \frac{Wt}{\mathrm{A}} = \frac{m\,g}{\mathrm{A}} = \frac{\rho\, vol\, g}{\mathrm{A}} = \rho\, g\, h$$

-Absolute pressure:-

$$P_t = P_a + \rho\, g\, h$$

$$P_t = 76 + h_{of\ a\ Hg\ column}\ in\, cm$$

*In case of many immiscible liquids:- $P_t = P_a + P_1 + P_2 + P_3$

-Atmospheric pressure:-

$$\mathrm{P}_a = \rho_{Hg} g h_{Hg}$$

-U-tube:-

$$\frac{\rho_1}{\rho_2} = \frac{h_2}{h_1}$$

-Manometers:-

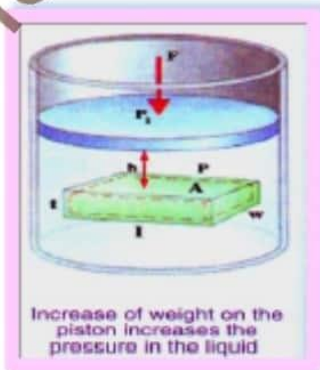
$$\Delta P = P_g - P_a = \pm \rho g h$$

$$\Delta P = P_g\ in\, cm\, Hg - P_a\ in\, cm\, Hg = \pm\, \Delta h_{Hg}\ in\, cm.$$

Pascal's principle:

If any pressure is applied to an enclosed liquid, it is transferred undiminished to all the points of the liquid as well as to the walls of container.

- If the liquid compressed below the piston is exposed to a pressure ($P_1 = \frac{F_g}{a}$) due to weight of the piston then the pressure at any point in the liquid becomes: $P_t = P_a + P_1 + \rho g h$
- When the pressure is increased by (ΔP) on the piston , the pressure on any point in the liquid will increase by the same value to become $P_t = P_a + \rho g h + P_1 + \Delta P$, as liquids are incompressible.
- N.B: The increase can't be observed since the liquid can't flow.



Increase of weight on the piston increases the pressure in the liquid

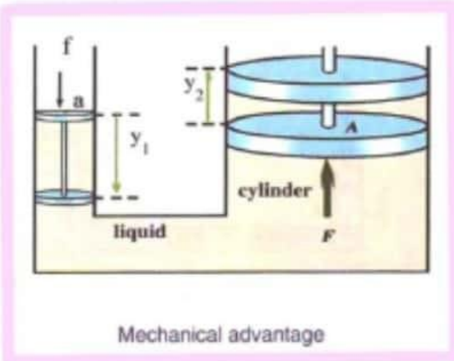
*** One of the applications on Pascal's principle is:**

The hydraulic press:

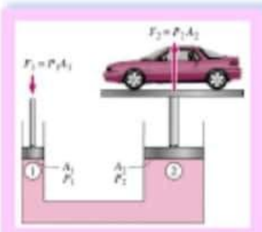
- Used to magnify a small force and carry heavy loads.
- A small force is exerted on the small piston of area (a) changes the pressure by (ΔP) which is then transmitted undiminished to the large piston of area (A) to produce a big force (F) which is enough to raise a car up.

$$\boxed{\Delta P = \frac{F}{A} = \frac{f}{a} \qquad \therefore \quad F = \frac{f\,A}{a} \rightarrow N}$$

- The little force is then magnified to become a strong one.



Mechanical advantage



- **The mechanical advantage of a press**:

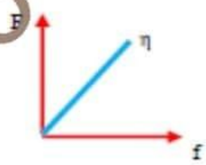
is the ratio between the resulting force & the applied one.

* **can be calculated as**: - the ratio between the mass carried by the large piston & the one acting on the small one = the ratio between the surface area of the large piston & that of the small one = the ratio between the square of the radius of the large piston & that of the small

one = the ratio between the square of the diameter of the large piston & that of the small one = the ratio between the displacement of the small piston to that of the large one. = The ratio between the speed of the small piston to that of the large one.

- Since the volume of the liquid displaced from the small piston (s) is equal to the one displaced to the large one (S) then $Vol = a \times s = A \times S$ where $\frac{a}{S} = \frac{A}{s}$ and $A \alpha \frac{1}{S}$

$$\boxed{\eta = \frac{F}{f} = \frac{Mg}{mg} = \frac{A}{a} = \frac{\pi R^2}{\pi r^2} = \frac{D^2}{d^2} = \frac{s}{S} = \frac{v}{V}}$$



- For a group of presses $\eta_{gr.} = \eta_1 \times \eta_2 = \frac{F_{final}}{F_{initial}}$

- $Efficiency\ of\ a\ press = \frac{W_{output}}{W_{input}} \times 100 = \frac{F\,S}{f\,s} \times 100$

- For an **ideal press, efficiency = 100 % since work output = work input**

- N.B:- For an ideal press $\frac{F}{f} = \rangle 1$, $\frac{P}{p} = 1$, $\frac{W}{w} = 1$

- A press may not respect Pascal's principle if it contains some air bubbles, as gases are compressible, or if it leaks leading to a liquid outflow.
- For a press to be at **equilibrium** (pistons stop moving) the pressure at two points at the same horizontal level inside the liquid must be equal, and it is not a must that both pistons be at the same level to achieve this.

Applications on Pascal's principle

1. Hydraulic press is used to magnify a small force to carry heavy loads.
2. Hydraulic brakes are used in cars.
3. Powerful hydraulic pistons are used to compress & shape metals.

1- What is meant by:

1. The mechanical advantage of a press is 80.

- 80 is the ratio between the resultant force & the applied one.

2. The efficiency of a press is 80 %.

- 0.8 is the ratio between the output work to the input work of the press.

<u>2- Give reasons:</u>

1. Hydraulic presses can lift large loads while acting upon them with small forces.

- Because according to Pascal's principle, pressure is transmitted undiminished through liquids and f/a = F/A so by increasing the area, the resultant force is magnified to keep the pressure constant.

2. In the hydraulic press, the motion of the small piston is faster than that of the large one.

- Because the liquid is incompressible so the volume displaced from the small piston = to the one reaching the large piston & as A/a = s /S & $A \propto 1/S$ The displacement of the small piston is greater as its area is smaller.

<u>* Solved examples:</u>

1. The area of the small piston of a press is 10 cm^2. If a force of 100 N acts on it & the area of the large piston is 800 cm^2 & g = 10 m/s^2. Calculate:

a) The mechanical advantage of the press.

b) The maximum mass carried by the large piston.

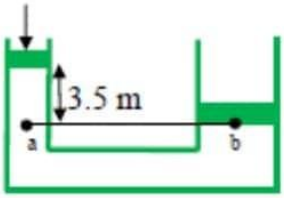
c) The distance moved by the small piston to move the large one along a displacement of 1 cm.

a) $\eta = \frac{A}{a} = \frac{800}{10} = 80$

b) $F = \frac{f \times A}{a} = \frac{100 \times 800}{10} = 8000\,N$, $M = \frac{F}{g} = \frac{8000}{10} = 800\,Kg$.

c) $s = \frac{F \times S}{f} = \frac{8000 \times 1}{100} = 80\,cm$.

2. For the shown hydraulic press, the mass of the large piston is 1300 Kg and its area 0.2 m^2. The small piston has a negligible mass & area 30 cm^2. Calculate the force applied on the small piston necessary to maintain equilibrium. ($\rho_{oil} = 780\ Kg/m^3$, $g = 9.8\ m/s^2$).



$$P_a = P_b$$

$$\rho g h + \frac{f}{a} = \frac{F}{A}$$

$$780 \times 9.8 \times 3.5 + \frac{f}{30 \times 10^{-4}} = \frac{1300 \times 9.8}{0.2}$$

$$f = 110.83\,N$$

Guide rules for problems

*Pascal's principle:

-Hydraulic press:-

$$P = \frac{F}{A} = \frac{f}{a}$$

-The mechanical advantage of the press:-

$$\eta = \frac{F}{f} = \frac{A}{a} = \frac{Wt}{wt} = \frac{R^2}{r^2} = \frac{y}{Y} = \frac{s}{S}$$

-For group:- $\eta_t = \frac{F_{out}}{f_{in}} = \eta_1 \times \eta_2$

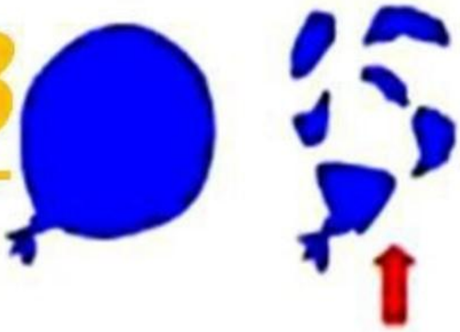
-Efficiency of press:- $\frac{F_Y}{f_y} \times 100\% = \frac{\text{work output}}{\text{work input}} \times 100\%$

1- Choose the correct answer:

1. In the hydraulic press the ratio between the resultant force to the applied one is ……..
   (1 – less than 1 – greater than 1)

2. In the hydraulic press the ratio between the resultant pressure to the applied one is……
   (1 – less than 1 – greater than 1)

3. In the hydraulic press the ratio between the output work to the input one is ………….
   (1 – less than 1 – greater than 1)

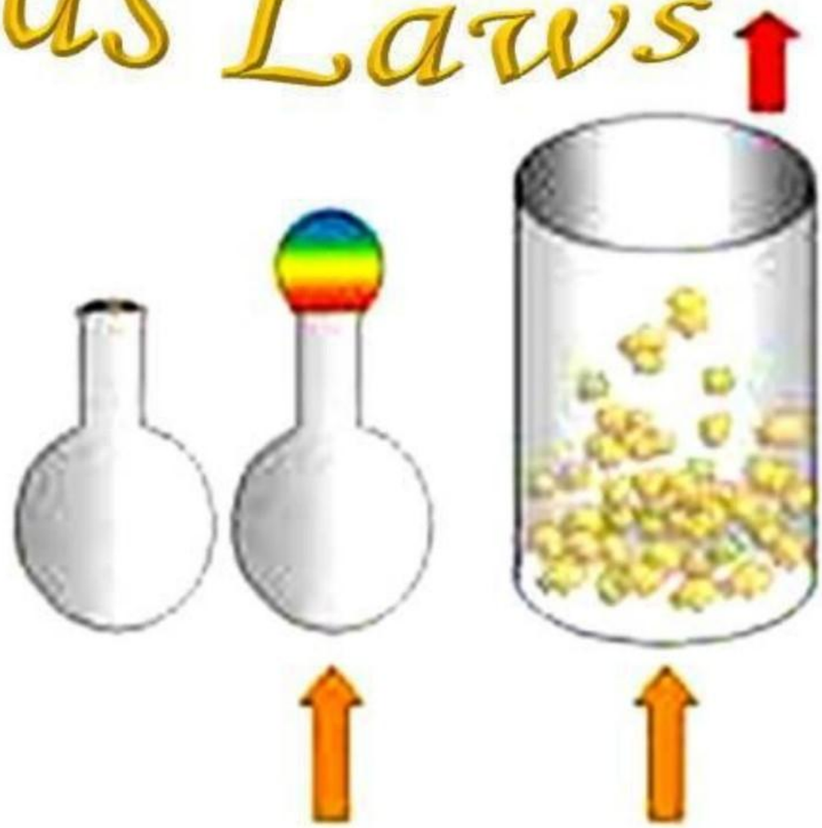


Unit 3

Heat

Chapter 5

Gas Laws



UNIT (3) HEAT CHAPTER (5) GAS LAWS

*** Brownian movement :- (random movement).**

- Illuminate a glass box by a strong light.
- Introduce smoke in it and observe by the aid of a microscope the motion of graphite particles. We observe that they move randomly.
- The particles of air moving in all directions in a **vibratory and translational motion** at different velocities collide against the graphite particles. When collision on one side is stronger than the other the last moves.
- Gaseous molecules always move randomly (in a haphazard motion) colliding against each other and against the walls of container elastically occupying its volume.

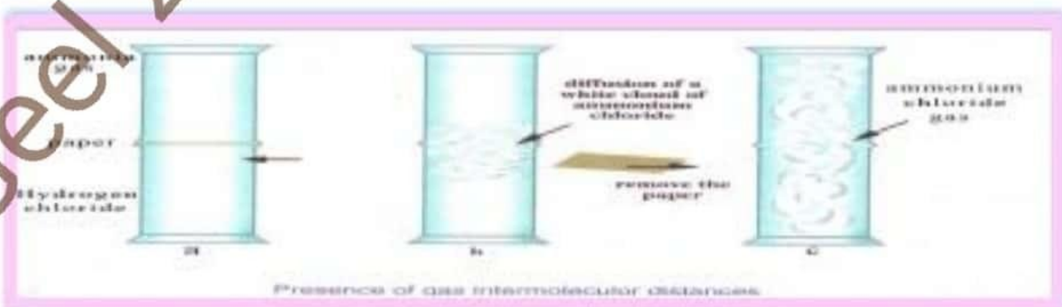
- How to prove the presence of intermolecular spaces:-

- A jar containing ammonia gas of low density is inverted on the one containing hydrogen chloride gas of higher density.

- A white cloud of NH_4Cl (ammonium chloride) is formed along the tubes.

- Although HCl is more dense it moves up diffusing in the intermolecular spaces of NH_3 and vice versa so they combine to form NH_4Cl.

-Intermolecular spaces are found between the molecules of gases and weak intermolecular forces allow them to move randomly in all directions.



Presence of gas intermolecular distances

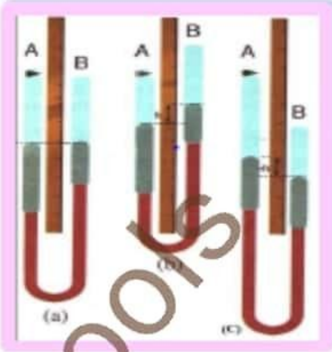
To study the relation bet volume (vol), pressure (P) of temperature (t) of a gas, one of the three variables must be fixed at a time.

1- Relation between Vol. and P. at constant (t°)

2- Relation between Vol. and t° at constant (P.)

3- Relation between P. and t° at constant (Vol.)

1- Relation between Vol. & P. at constant t:- Boyle's law:



* Exp:-

1- Open the tap of the burette B after filling the tube A with Hg.

2- Move A up & down until the Hg level becomes equal in both A and B , then measure the volume of air in the burette Vol_1 whose pressure $P_1 = P_a$ after closing the tap.

3- Raise the tube A up and measure the new air volume Vol_2 of pressure $P_2 = Pa + \rho g h$.

4- Move the tube A down & measure the volume of air in the burette V_3 of pressure $P_3 = Pa - \rho g h$.

5- Repeat step 3 & 4 for several times & draw the relation Vol Vs $\frac{1}{P}$

$\boxed{\therefore Vol \ \alpha \frac{1}{P}}$ & $\boxed{P \times Vol = cont.}$ or $\boxed{\frac{P_1}{P_2} = \frac{Vol_2}{Vol_1}}$

Boyle's law :-

"For a certain mass of gas, its volume is inversely proportional to its pressure provided that its temperature is constant".

N.B:- $CaCl_2$ is added over Hg to dry air.

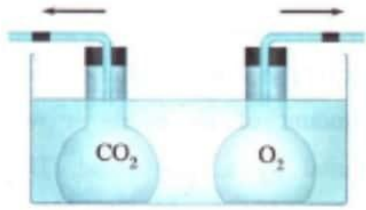
- The motion of the tubes must be slow to keep t° constant.

2- The effect of temperature change on the volume at constant P:

Exp :- To show the effect of t° on equal Vol. of different Gases :-

- Get two flasks of similar volumes fitted with 2 narrow glass tubes each containing a thread of Hg.

- Fill one with O_2 & The other with CO_2.
- Dip both flasks in a hot water bath.
- We observes that the Hg threads move similarly in both.
- This proves **that equal volumes of different gases kept under constant pressure expand similarly for a similar t° rise.**
- These are said to have the same coefficient of cubic expansivity.



* **Coefficient of cubic expansivity (α_{vol}):**

"Is the amount of increase in a unit volume of a gas at 0°C if its t° is raised by 1°C at constant pressure"

- The coefficient of cubic expansivity α_{vol}:-

$\therefore$ ΔV depends on :-

Δt (change of t°.)

$V_{ol\,0}°c$ (Volume of the gas at 0°C)

and it was found experimentally that :-

$\Delta V_{ol} \propto V_{ol} 0°$ & $\Delta V_{ol} \propto \Delta t$

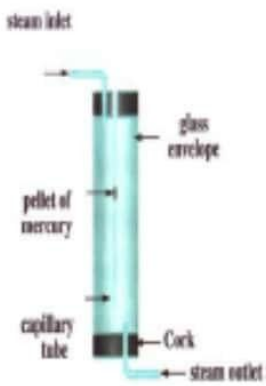
$\Delta V_{ol} \propto V_{ol} 0° \Delta t$ (α_{vol} is the constant)

$$\therefore \quad \boxed{\alpha_{Vol} = \frac{\Delta Vol}{Vol_0 \, \Delta t}}$$

* Determination of α_{vol} practically:- "Charles's law "

(Relation between the volume and temperature of a gas at a constant pressure):

- get a glass tube 30 cm. Long & 1 mm in diameter closed from its lower end.
- A Hg (H_2SO_4) drop is introduced to trap air , dry it & keep its pressure constant.
- The tube is inserted in a jar full of ice starting to melt (at 0°C).
- Measure the length of air column, this is proportional to its volume ($V_{ol\,0}°c$) since its cross section is uniform.
- Remove ice & water & start passing vapor at 100°C through the jar.



- Wait for a while & then measure the length of the air column. ($V_{ol\ 100}$°c).

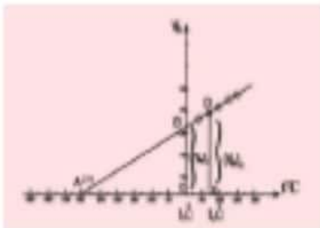
$$\alpha_V = \frac{V_{ol\,100} - V_{ol\,0}}{V_{ol\,0}(100-0)} = \frac{V_{ol\,100} - V_{ol\,0}}{V_{ol\,0} \times 100} = \frac{AL_{100} - AL_0}{100\,AL_0}$$

- For all gases α was found to be equal $\frac{1}{273}$ per degree.

N.B: Precautions while performing Charles experiment:

1. The narrow tube must be of a uniform cross sectional area, to be able to substitute the volume by length and facilitate the calculation of α_{Vol}.
2. Use a drying agent to remove water vapour which is not an ideal gas from air.
3. Do not measure the volume (length) unless the liquid drop rests at equilibrium completely to grant that the pressure is constant = P_a.

<u>Charles's law:-</u>



"For a certain mass of gas, its volume increases by $\frac{1}{273}$ of its volume at 0 °C for each degree rise in temperature provided that its pressure is kept constant."

<u>3- The effect of temperature change on pressure at a constant Volume:-</u>

<u>Exp :-</u> To show the effect of t° on P. at constant Vol.

- A glass flask containing air is fitted with a U shaped tube containing Hg.
- Hg in both branches of the tube has the same level. (fig. a)

(a) (b) (c)

- Put the flask in a hot water bath, the gas expands and pushes the Hg which rises up in branch B (fig. b).
- Add Hg to get the Hg in A back to its initial level.

- Now the Hg level at B is higher than that at A by (h) cm. which proves that the pressure of gas increases by heating (fig. c).
- Repeat the experiment several times using equal volumes of different gases.
- We find that **different gases increase their pressures similarly, for similar t° rise provided that their volumes are kept constant.**

*** Coefficient of pressure expansivity at constant Vol. (β_P)**

" Is the amount of increase in the unit pressure of a gas at 0°C if its t° increases by 1°C at constant volume.

- The coefficient β_P :- $\because \Delta P$ depends on Po & Δt .

Where $\Delta P \propto P_o$ & $\Delta P \propto \Delta t$

$\therefore \Delta P \propto Po\,\Delta t$

$$\therefore \boxed{\beta_P = \frac{\Delta P}{Po\,\Delta t}}$$

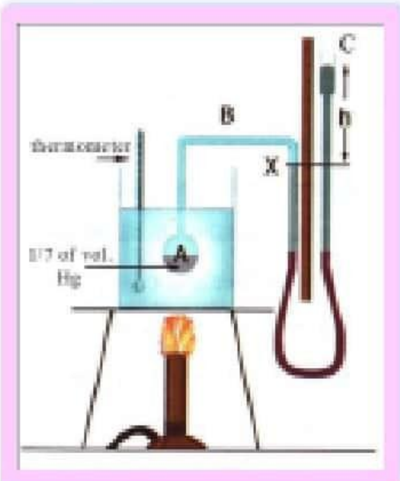
*** Practical determination of β_P "Pressure's law":-**

(Relation between the pressure and temperature of a gas at a constant volume):

- Jolly's instrument: (Gaseous thermometer)

- It consists of:

- A flask filled to $\frac{1}{7}$ of its volume with Hg to overcome the expansion of glass.
- The flask is connected to a tube (B) which is connected through a rubber tube to another barometric tube (C) filled with Hg.
- A vertical graduated scale & a thermometer.



Procedure :-

1- Dip the flask in melting crushed ice

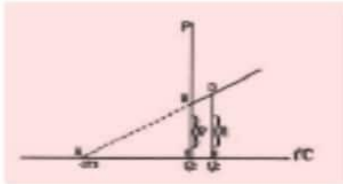
2- Wait for a while to allow the t° of the dry air inside the tube to reach 0 °C.

3-Move the tube C up & down until the Hg in tube B reaches a certain point (x).

4-Measure the difference of Hg levels in B & C, this is called (h).

5-Pressure of air in the flask is calculated as:

$P_o = P_a - \rho g h$ or $(P_a - h)$



6-Place the flask in boiling water & wait for a while until air reaches 100 °C.

7-Move C until the level of Hg in B returns to the same point (x) to keep the volume of the gas constant.

8- Measure the difference in Hg levels between B & C call it (h_1).

9-The pressure of air is now calculated as :-

$P_{100} = P_a + \rho g h_1$ or $(P_a + h_1)$

The pressure expansivity of a gas at constant volume β_p is given as :-

$$\boxed{\beta_p = \frac{P_{100} - P_o}{P_o \times 100}}$$

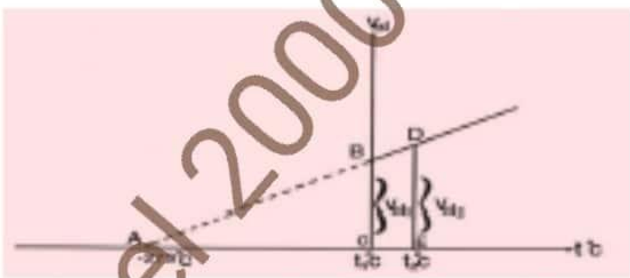
N.B :- β_P for all gases $= \frac{1}{273}$ for each degree rise in t°.

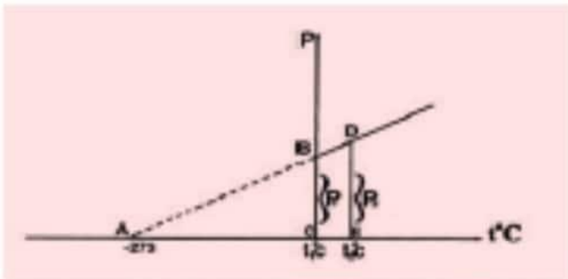
$\alpha_{Vol} = \beta_P$ for all gases.

*** Pressure's law :-**

" For a certain mass of gas, the pressure increases by $\frac{1}{273}$ of its value at 0 °C, for each degree rise in temperature, provided that the volume is kept constant."

* Graphs representing the relations between (P & t°) & (Vol & t°) & their uses to find the absolute zero (zero Kelvin)





- By plotting the results obtained in the previous experiments we obtain the graphs from which we can find that :-

The extension of both graphs will intersect with the t° axis at - 273°C which is equivalent to 0° **Kelvin or (absolute zero)** : temperature at which both volume and pressure of a gas vanish theoretically.

N.B :- The gas doesn't reach this t° practically since it liquefies & solidifies before reaching it.

$\therefore$ - 273 ° C = 0 ° Kelvin.

0 ° C = 273 ° K

100 ° C = 373 ° K.

T ° K = T ° C + 273.

*** Other forms of Charles's law & Pressure's law :**

- From graph 1, Δ ABC & ADE are similar

$$\frac{BC}{DE} = \frac{AC}{AE}$$

$$\boxed{\frac{Vol_1}{Vol_2} = \frac{t_1+273}{t_2+273} = \frac{T_1}{T_2}}$$

$\therefore$ Vol α T (volume α absolute t°). $\boxed{\frac{Vol}{T} = const.}$

*** Charles's law :-**

- At constant pressure the volume of a fixed gaseous mass, is directly proportional to its temperature on the Kelvin scale.

-From graph 2.

$$\boxed{\therefore \frac{P_1}{P_2} = \frac{t_1+273}{t_2+273} = \frac{T_1}{T_2}}$$

$\therefore$ P α T (pressure α absolute t°) $\boxed{\frac{P}{T} = const.}$

*** Pressure's law:-**

- At constant volume the pressure of a fixed gaseous mass is directly proportional to its temperature on the Kelvin scale.

* **General gas law:**

$\therefore V_{ol} \propto \frac{1}{P}$ Boyle's law. & $V_{ol} \propto T$ Charles's law

$\therefore V_{ol} \propto \frac{T}{P}$ $\therefore \frac{V_{ol} P}{T} = \text{Constant}$

$\boxed{\frac{P_1 V_{ol\,1}}{T_1} = \frac{P_2 V_{ol\,2}}{T_2}}$ **General gases law.**

N.B :- The law is applied on ideal gases when:

- T° is in Kelvin. (absolute temperature).
- Gas is at S.T.P. (P = 76 cm Hg , T = 273 °K)
- V_{ol} P = constant T.

Constant = R = 8.31 J/mole °K & is known as the universal gas constant.

* **Rules deduced from the general gas law for some special cases:**

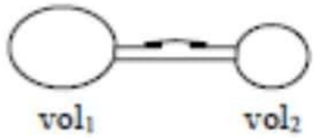
- $\because \frac{P_1 V_{ol\,1}}{T_1} = \frac{P_2 V_{ol\,2}}{T_2}$ $\therefore \frac{P_1 m}{\rho_1 T_1} = \frac{P_2 m}{\rho_2 T_2}$ *and for a certain mass of a gas*

the general gas law can be written in terms of ρ as : $\boxed{\frac{P_1}{\rho_1 T_1} = \frac{P_2}{\rho_2 T_2}}$

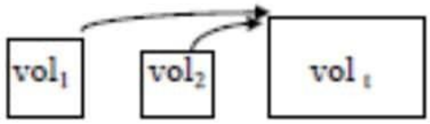
-In case of leakage or introduction of a gas in a container :

$\because \frac{P_1}{\rho_1 T_1} = \frac{P_2}{\rho_2 T_2}$ $\therefore \frac{P_1 Vol}{m_1 T_1} = \frac{P_2 Vol}{m_2 T_2}$ *and as Vol. is constant then* $\boxed{\frac{P_1}{m_1 T_1} = \frac{P_2}{m_2 T_2}}$

-In case of mixing: $\boxed{\frac{P_1 Vol_1}{T_1} + \frac{P_2 Vol_2}{T_2} = \frac{P_1 Vol_1}{T_1} + \frac{P_2 Vol_2}{T_2}}$



or $\boxed{P_1 Vol_1 + P_2 Vol_2 = P_T Vol_T}$



∗ Remember:-

1- What is meant by:

1. The coefficient of volume expansivity of a gas = $\frac{1}{273} K^{-1}$.

- $\frac{1}{273}$ is the amount of increase in the unit volume of the gas than its volume at $0^{\circ}C$ for each degree rise in temperature , provided that pressure is kept constant.

2. The coefficient of pressure expansivity of a gas is 0.00366 K^{-1}.

- 0.00366 is the amount of increase in the unit pressure of the gas than its pressure at $0^{\circ}C$ for each degree rise in temperature , provided that volume is kept constant.

3. The universal gas constant =8.31 J/mole°K.

- 8.31 J is the heat energy needed to raise the t° of one mole of a gas by one °K.

∗ Solved examples:

1. If the volume of a gas at 0 °C is 450 cm^3. What will be its volume at 91°C given that pressure is constant.

Vol α T $\qquad \therefore \frac{Vol_1}{Vol_2} = \frac{T_1}{T_2} \qquad \therefore \frac{450}{Vol_2} = \frac{273}{91+273}$

$Vol_2 = 600\ Cm^3$.

2. If a half liter of H_2 is heated from 10° to 293 °C find its final volume.

$$\frac{Vol_1}{Vol_2}=\frac{T_1}{T_2} \qquad \frac{0.5}{Vol_2}=\frac{10+273}{293+273} \qquad \therefore\ Vol_2 = 1 \text{ liter.}$$

3. If the pressure of a gas is 59.8 cm Hg at 26 °C, what will be its pressure at 130°C. at a constant volume ?

$$\frac{P_1}{P_2}=\frac{T_1}{T_2} \qquad \frac{59.8}{P_2}=\frac{26+273}{130+273} \qquad \therefore\ P2 = 80.6 \text{ cm Hg.}$$

4. If the volume of a gas is 380 cm^3 at 27 °C & 60 cm Hg. Find its volume at STP.

$$\frac{Vol_1P_1}{T_1}=\frac{Vol_2P_2}{T_2} \qquad \therefore\ \frac{380\times 60}{273+27}=\frac{Vol_2\times 76}{273} \qquad \therefore Vol_2 = 273 \text{ cm}^3.$$

5. 15 liters of N_2 at 12 cm Hg & an 10 liters of O_2 gas at 50 cm Hg. If both are placed together in a closed vessel of volume 5 liters , find the pressure of the mixture if the t ° is Kept constant.

* After mixing each gas occupies a volume of 5 liters.

$\therefore$ For H_2 :- $P_1 Vol_1 = P_2 Vol_2$ For O_2 :- $P_1 Vol_1 = P_2 Vol_2$

$12 \times 15 = P_2 \times 5$ $10 \times 50 = P_2 \times 5$

$P_2 = 36$ cm Hg $P_2 = 100$ cm Hg

$P_T = P_1 + P_2 = 36 + 100 = 136$ cm Hg.

Or $(P_T\, Vol_T = P_1\, Vol_1 + P_2\, Vol_2)$

Guide rules for problems

Boyle' law: $\frac{P_1}{P_2} = \frac{Vol_2}{Vol_1}$

Charles law: $\frac{Vol_1}{Vol_2} = \frac{t_1+273}{t_2+273} = \frac{T_1}{T_2}$

$$\alpha_{Vol} = \frac{\Delta Vol}{Vol_0 \, \Delta t} \qquad \alpha_v = \frac{V_{ol\,100} - V_{ol\,0}}{V_{ol\,0}(100-0)} = \frac{V_{ol\,100} - V_{ol\,0}}{V_{ol\,0} \times 100} = \frac{AL_{100} - AL_0}{100\,AL_0}$$

Pressure's law : $\frac{P_1}{P_2} = \frac{t_1+273}{t_2+273} = \frac{T_1}{T_2}$

$$\beta_p = \frac{\Delta P}{Po\,\Delta t} \qquad \beta_p = \frac{P_{100} - P_o}{P_o \times 100}$$

Absolute temperature : T ° K = T ° C + 273.

General gas law: $\frac{P_1 V_{ol\,1}}{T_1} = \frac{P_2 V_{ol\,2}}{T_2}$

General gas law in terms of density: $\frac{P_1}{\rho_1 T_1} = \frac{P_2}{\rho_2 T_2}$

In case of leakage or pumping of a gas into a container: $\frac{P_1}{m_1 T_1} = \frac{P_2}{m_2 T_2}$

In case of mixing gases in one container: $P_1\,Vol_1 + P_2\,Vol_2 = P_T\,Vol_T$

In case of mixing gases in separate containers: $\frac{P_1\,Vol_1}{T_1} + \frac{P_2\,Vol_2}{T_2} = \frac{P_3\,Vol_1}{T_1} + \frac{P_3\,Vol_2}{T_2}$

1- Complete:

1. The normal body temperature is .... ° k, while the boiling point of water is .... ° k.
2. The quantity of material containing a number of particles called Avogadro's number is called........ and if this quantity is multiplied by the specific heat it produces............
3. When the pressure is constant the volume of the gas is .... proportional to ....
4. The coefficient of volume expansivity of a gas under .... equals ....

2- What is meant by:

1. The coefficient of volume expansivity of a gas is 1/273.

....

....

2. The coefficient of pressure expansivity of a gas is 0.00366 K^{-1}.

....

....